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## Spinal Anticipation and Cortical Correction: Coordination of Movements (1930)

*Peter J. Beek and Onno G. Meijer*

The present brief paper, titled the "Coordination of Movements," was written by Bernstein in 1930 for the *Grand Medical Encyclopedia*. To the uninformed reader the paper may seem little more than a rather routine summary of the topic of coordination for medical doctors. Yet in reality we are dealing with quite a significant publication, both in terms of the implicit position Bernstein is adopting with regard to the prevailing theories of his times, and in terms of the development of his own thinking about coordination.

The year 1930 may be viewed as the beginning of the era of political correctness in Soviet academia (Bongaardt, 1996; cf. Kozulin, 1984). In line with the doctrine of "dialectical materialism," neuropsychologists were forced to define the materialist foundations of their discipline. This was far from straightforward. Although Bechterev had died in 1927, possibly killed by the authorities, his "reactology" was still taught at nearly all universities. Pavlov, in Leningrad, was a force to be reckoned with because of his 1904 Noble prize (cf. Grigorian, 1974), but as he was opposed to communism, his position was far from secure. In Moscow, a young group of scientists around Kornilov tried to create a typical Marxist theory of reflexes. For some in this group, like Luria and Vygotsky, it was evident that the theories of Bechterev and Pavlov were inadequate for dealing with higher activities such as thinking, remembering, attending, and planning (cf. Van der Veer & Valsiner, 1991).

While Bernstein remains silent in this 1930 paper about the choice Soviet neuropsychology was facing, it is in our opinion far from trivial that he highlights the work of Sherrington, while leaving the research of Bechterev, Pavlov, and the Kornilov school unmentioned. Remarkably, he does so in an article on coordination written for an encyclopedia, that is, a source of objective, established knowledge. Later, during the anti-Semitic campaign at the end of the '40s, Bernstein's practice of quoting foreign authors while ignoring established Soviet scientists would contribute to his public denouncement and the shutdown of his laboratory in Moscow.

### **Complete behaviors dormant in the spinal cord**

Historically, Bernstein's 1930 paper is important in terms of the development of his thinking in that it represent the first step toward his groundbreaking

article on “The problem of the interrelation between co-ordination and localization” (1935/1988). Never before (cf. Feigenberg, 1988) had Bernstein addressed the topic of coordination head on. In the 1920s he had been predominantly concerned with the development of new movement registrations techniques, such as “kymocyclography.” With the help of these techniques, he was able to measure human motor behavior in much greater detail than was customary in his times (Bongaardt, 1996).

These detailed measurements played an instrumental role in the formation of Bernstein’s ideas about coordination. In 1927 he came to the conclusion that skilled rhythmic movements such as professional filing movements are characterized by a “high degree of automation, mechanical simplicity and lawful structure” (p. 789; cf. Bongaardt, 1996). In 1929 he started to depart from such a mechanistic view in a paper with Popova on piano playing, in which he noted that “with the slow, middle and fastest paces, we are dealing with three totally different dynamical constructions” (p. 422; cf. Bongaardt, 1996). And in his classical 1935 paper he realized that “successive movements of cyclical nature never exactly repeat themselves” (1935/1988, p. 48). Then, he concluded that there can be no straightforward relation between the central signal to perform a movement and the resulting movement itself.

The present article precedes this conclusion in that it highlights the role of the spinal cord in attuning the “primary impulse” (i.e., the impulse that causes a muscle to contract) to the prevailing task constraints. Bernstein’s 1930 view of spinal cord function appears to be strongly influenced by Sechenov’s idea (1863/1965; cf. Mecacci, 1979) that complete behaviors lay dormant in the spinal cord, to be unleashed by cortical disinhibition. In Bernstein’s view, the spinal cord is responsible for “primary coordination,” exploiting the principles of reciprocal innervation identified by Sherrington.

Although his portrayal of the spinal cord as a relatively autonomous lower level of organization is still interesting today, and certainly contains an element of truth, the importance of higher brain centers should not be underestimated. In this respect it is unfortunate that Bernstein chooses as his example a man who plans to lift a ball, a feather, and then a 16-kg dumbbell. Knowledge of balls, feathers, and dumbbells is certainly of a supraspinal nature, and one recognizes here that in 1930 Bernstein is not yet clear on the division of labor between the different levels of movement organization in the nervous system (cf. Bernstein, 1991/1996). Nevertheless, the general idea that the spinal cord is in part responsible for “anticipations” and “ante factum” corrections (Sporns & Edelman, 1998) will remain part of his theory.

### **“No movement can be entirely planned from its very beginning.”**

In the second part of his 1930 paper, Bernstein places “primary coordination” within a larger context by emphasizing the “incomparably larger role” in coordination that is being played by secondary impulses, i.e., “secondary coordination.” Continuous corrections of the impulses that are sent to the muscles result from sensory information. Bernstein amplifies his presentation of the crucial role of sensory information in coordinated movement by summing up various sensory channels and the neurological disorders that may follow from their impairment. This summary proceeds from the spinal cord all the way up to the cerebellum and the cortex, both deemed crucial organs in the process of secondary coordination.

Considering its year of publication, this summary is remarkably complete and accurate, testifying to the fact that from early on in his career Bernstein was interested in the role of sensory corrections in coordination and its pathology. What is remarkable is that the only explicit mention he makes of the cortex is in this context of secondary corrections. True, the cortex participates in “the highest, most precise coordination of movements,” but Bernstein does not focus on the cortex as an originator of impulses. Later, he will refine this Sechenov-inspired reversion of spinal and cortical roles, then stressing that the ability to take the initiative is indissolubly linked to the cortex (cf. 1991/1996). From a historical viewpoint, it is interesting to see how Bernstein used spinal autonomy as a stepping stone in developing his theory of coordination.

And of course, even today the problems of the nature and location of anticipation and correction in the nervous system are still far from resolved. While Bernstein’s emphasis on spinal anticipation and movement correction by the higher brain centers is unlikely to tell the whole story, it may provide a healthy reflection point for current researchers who start from the default assumption that the higher brain centers predominantly operate in feedforward mode and the spinal cord in feedback mode.

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## Coordination of Movements\*

*N.A. Bernstein*

Coordination<sup>1</sup> of movements (from Latin “coordinato”—putting into order) is a common organization of impulses to separate muscle groups in time and space directed at achieving a particular motor effect. The proven fact of participation of virtually all parts of the central nervous system in the coordination of movements suggests an extreme complexity of the coordinative functioning of the organism. In essence, one may say that everything that makes any simple or complex human movement different from a twitch<sup>2</sup> of a separated frog muscle is fully defined by the coordination of movements.

Each original<sup>3</sup> motor impulse sent to a muscle within a healthy organism from spinal cord cells is in itself coordinated with or adjusted to a stimulus that brings about this particular movement. If a man plans to lift a ball, a feather, and then a 16-kg dumbbell, he sends to his muscles absolutely different impulses depending on the expected resistance that is going to be met by each of these movements. In an overwhelming majority of cases, such primary coordination of movements (or coordination of the primary impulse) is performed by the lower, spinal levels of the central nervous system. This is confirmed, for example, by the fact that a decapitated frog shows limb movements during the “wiping reflex”<sup>4</sup> that are strictly coordinated with the skin area that is being irritated and are modified instantaneously when a different area of the body begins to be irritated.

Even the primary coordination of movements occurs to represent a very complex totality of mechanisms. If one considers the simplest joint with only one degree of freedom of mobility (see *Movements*<sup>5</sup>), it occurs that, during any move-

ment, the activation of a muscle is accompanied by a supporting activation of its synergists and suppression of its antagonists. This phenomenon, termed reciprocal (i.e., mutually inverse) innervation was already noticed by Bell (1836) and studied in detail by Sherrington in the beginning of the 20th century.

Sherrington has shown that, in a mammal (the cat), this phenomenon is of a purely spinal origin. In joints with a richer mobility, reciprocal innervation turns into a more complex process of redistribution of forces among all the muscles crossing the joint. Sherrington has also shown that an activation of the flexors of one hindlimb of an animal is accompanied by a simultaneous inhibition of the extensors of the other hindlimb. Moreover, a flexion reflex of a hindlimb induced by a stimulus applied to a peripheral area of the body can be suppressed by an activation of extensors of the contralateral hindlimb. It is quite possible that these phenomena of bilateral mutually inverse dependence are related to the most basic components of the mechanism of walking.

An incomparably larger role in coordination of movements is being played by secondary impulses (secondary coordination). No movement can be entirely planned from its very beginning; the process of an already initiated movement is accompanied by continuous corrective impulses sent by the central nervous system to all the muscles directly or indirectly involved in the movement.

Secondary coordination of movements is a reflex process<sup>6</sup>. The centripetal half-arc<sup>7</sup> of this reflex is formed with participation of a majority of the sensory apparatuses of the body, first of all the proprioceptive apparatuses (ending organs in tendons, muscles, and joint capsules; their route is via the dorsal columns of the spinal cord), then organs of deep and superficial cutaneous sensitivity (their routes are the tractus spino-thalamicus and tractus spino-cerebellaris), labyrinths, and eyes. Central apparatuses of the secondary coordination of movements are supraspinal; they involve the cerebellum, the visual colliculi, midbrain nuclei, and the frontal lobes of the large brain.

The proprioceptive reflex is impaired or destroyed during atrophy<sup>8</sup> of the dorsal spinal columns (Goll tract and Burdach tract) leading to the development of *ataxia*. The role of this reflex can be best understood on the basis of an analysis of the impairments during ataxia associated with *tabes dorsalis*. In healthy humans, this role can be described as providing for eutopia (correct hitting of a required point target) and eumetria (correct measure of movement). Thus, this mechanism is mostly involved in regulation of the spatial coordination of movements; its impairments lead to movements becoming of a wrong size (dysmetria), and losing their accuracy (dystopia) and confidence. Secondary coordination of movements related to conduction in the lateral spino-cerebellar pathway and, in the brain, to the functioning of the cerebellum, pons, labyrinths, and frontal lobes, is much more complex, and its significance is presently best understood in relation to the mechanisms of maintaining postural equilibrium.

During cerebellar disorders, the kinesthetic sense (i.e., the perception of position, direction, and effort of a movement) is typically not impaired, while standing (Rhombert symptom) and walking are. Walking becomes unsteady, a tendency to fall (*astasia*) emerges, it becomes harder to change the direction of walking, etc. The normal coordination of movements of other parts of the body is also affected, in particular the coordination of the eyes (*nystagmus*) and arms (*adiadochokinesis*). After complete extirpation of the cerebellum, walking rhythm in monkeys has been noticed to suffer (limb movements in an abnormal sequence and with abnor-

mal pauses; clumsy, bouncy, and interrupted running), which suggests that the cerebellar apparatus participates in the realization of temporal or rhythmic coordination of movements, i.e., eurhythmia.

Ear labyrinths play a very important role in the secondary coordination of movements together with the cerebellum. Besides their main function of a sensory organ defining the directions of gravity and of body acceleration in space, and participating in the maintenance of an equilibrium, the labyrinths play a very intimate although still unclear role in the maintenance of the tone of neck muscles and limb extensors. Disorders of the labyrinths lead to loss of postural equilibrium, lightheadedness, persisting circling on one spot, etc.

The highest, most precise coordination of movements is realized with the closest participation of the cortex of the large hemispheres. The occipital lobes make visual coordination possible while the frontal lobes affect dexterity<sup>9</sup> and internal consistency of movements (the mechanism is yet unknown). Disorders of the central left gyrus and the corpus callosum may lead to the development of *apraxia*, i.e., an impairment of the ability of perform complex, purposeful sequences of movements. Specific, local disorders of movement coordination related to disorders of the cerebral cortex also include *aphasia* and *agraphia*, paraphasia, and *paragraphia*<sup>10</sup>.

## Notes

\*The paper was translated by Mark L. Latash and edited for clarity. It appeared in the *Bol'saja Medicinskaja Enciklopedija* [Grand Medical Encyclopedia], Volume 13, pp. 755-757. Moscow: Medgiz (1930).

<sup>1</sup>Note that Bernstein's 1930 definition of "coordination" is of a hierarchical nature: Coordination is imposed by some mechanism that does the "putting into order." From 1935 onward, his concept of coordination will be much more "self-organized" (to use the modern term), but he will continue to postulate the existence of "organs of the central nervous system [that] could be addressed as automatizers" (Sporns & Edelman, 1998, endnote E).

<sup>2</sup>The emphasis here is on "twitch," as opposed to the repertoire of spinal behaviors that are exemplified by the wiping reflex (see below).

<sup>3</sup>Both in this "original" motor impulse and in the "stimulus" later in the same sentence, the exact division of labor between the spinal cord, the cortex, and phenomena that stem from the environment remains unclear, testifying to the fact that Bernstein was on his way to creating a theory of coordination.

<sup>4</sup>The functional nature of the wiping reflex continued to amaze researchers from Boyle and Locke onward (Meijer et al., 1988) through the present time (Bizzi et al., 1992; cf. Fukson et al., 1980). In our opinion, it is this kind of behavior that allows for thinking in terms of "spinal anticipation" and of which we state, at the end of our introduction, that its nature is far from being resolved.

<sup>5</sup>Italics refer to other articles in the Grand Medical Encyclopedia. The one on Movements is by Bernstein himself. Feigenberg (1988) gives the following reference: N. Bernštein: Dvizenija (Bewegungen). *Bol'saja Medicinskaja Enciklopedija* (Große Medizinische Enzyklopädie), Bd. 8, S. 451-474, 1929.

<sup>6</sup>This is where one would have expected a reference to Pavlov. It is conspicuously missing. One wonders in how far Bernstein was planning in 1930 to overthrow Pavlov, counting on a victory of the Kornilov school (with whom he was cooperating), and the demise of Pavlovianism. In 1930, Pavlov's position may have appeared weak not only because of his anti-communism but also because of the mechanistic nature of his theory (from

1930 until 1950, mechanicism was frowned upon in the Soviet Union). If so, it was the miscalculation of his life, the spectre of (neo)Pavlovianism haunting him even when he was buried (Bongaardt, 1996).

<sup>7</sup>This notion of “half-arc” suggests that there is another half. It is not before 1935, however, that Bernstein uses the term “reflex ring” to attack Pavlov’s views (cf. 1935/1988).

<sup>8</sup>Note that Bernstein occupied himself with the pathology of movements long before his first publications on the subject (cf. Meijer & Wagenaar, 1998; Wagenaar & Meijer, 1998).

<sup>9</sup>This is typical of Bernstein. There is no way the reader could have had an inkling about what he meant by “dexterity” before his book “On Dexterity and Its Development” (1991/1996). We can see that Bernstein was very much aware of his underemphasizing the role of the cortex in this 1930 paper on coordination; his dropping of the empty term “dexterity” forms a slot to be filled in later.

<sup>10</sup>The reader is left with a feeling of dissatisfaction. One would expect some content here, for instance on the division of labor between the spinal cord and the cortex, but the paper abruptly ends after this summing-up of forms of pathology. In that respect, the paper works as an appetizer. Perhaps that’s how Bernstein wanted it. From 1930 onward, it may have been expedient in the Soviet Union to first present new ideas as innocently as possible. No authority could deny that he summed up current knowledge of coordination while the implicit attack on Pavlov (the relative autonomy of the spinal cord, and the half-arc which appears to be part of a ring) remained completely hidden to the uninitiated.

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 (Also see references to the article “Movements”)

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